EPSTEIN & SCHWARTZ

An Investigation of Eye-Bars

Civil Engineering

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AN INVESTIGATION OF EYE-BARS

BY

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AND
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This is to certify that the thesis prepared in the Department of Theoretical and Applied Mechanics by ABRAHAM SOLOMON EPSTEIN and LLOYD SCHWARTZ entitled An Investigation of Eye-Bars is approved by me as fulfilling this part of the requirements for the degree of Bachelor of Science in Civil Engineering.

H. F. Moore
Instructor in Charge.

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Ira O. Baker
Professor of Civil Engineering.

Table of Contents.

Introduction

Increased loads on some of the existing wrought iron structures give rise to the question whether their design is safe under the present changed conditions, or whether they should be replaced by steel structures.

The majority of tension members in the old bridges consists of wrought iron eye-bars. The experimental knowledge in regard to the properties of wrought iron eye-bars and their method of failure is not extensive; at the same time the principles of modern economy demand an accurate determination of actual conditions.

In view of these facts this thesis was undertaken for the purpose of investigating:

1) The distribution of stresses in the eye-bar heads;

2) The properties of wrought iron in the form of eye-bars as compared with its properties in the form of small specimens;

3) Physical properties of wrought iron after long service in a railroad bridge.

Theory and Available Data

The published data on eye-bar tests made up to the present time is comparatively small. Several tests and investigations of the steel and iron eye-bars were made for the purpose of:

1) Theoretical determination of stresses in the eye-bar heads;

2) Establishing the proper proportion between the eye bar heads and pins;

3) Observing the properties of steel in the form of eye-bars as compared with its properties in the form of small specimens;

4) Observing the distribution of stresses in the eye-bar heads;

5) Observing the effects of the pin clearances.

Most of the tests and investigations in which the data have been published were performed during the period 1870-1880 and are of little value for the comparison with the results of this thesis because of the difference in purpose and conditions

William H. Burr.

Mr. W. H. Burr worked out a number of complicated formulas which give the

approximate distribution of stresses in the eye-bar heads. He developed the formula

$$f = c\left(\frac{R+r^2}{r^2}\right)$$

where "f" is the intensity of hoop tension at a distance "r" from the centre of the eye, "R" is the exterior radius of the head, and "c" is a constant.

From this formula it can be seen that the intensity of the hoop tension decreases quite rapidly as the distance from the centre of the eye increases.

In designing the head Mr. Burr shows that the critical section in the head of the bar is at an angular distance of about 35-40 degrees on each side of the axis of the bar, and at this point the width of metal on each side of the pin should be about $\frac{7}{8}$ that of the body.

C. Shaler Smith

Mr. C. Shaler Smith in 1877 endeavored to prove experimentally what Mr. Burr determined theoretically. He performed a number of tests with the following conclusions:

1) A pin 60 percent the width of the bar is the smallest which will

invariably break the bar or develop its full strength.

2) As the relative proportion of the diameter of pin to width of bar increases more metal is required in the section across the eye.

3) Shape of the eye-bar head required to give a slightly higher factor than the bar itself, depends entirely upon the material and mode of manufacture.

Frederick H. Lewis.

Mr. Lewis conducted a number of tests upon a large number of annealed steel eye-bars in order to observe the differences in ultimate strength of full sized bars and small specimens of the same material.

His tests show that the bars of moderate sections (4 to 20 square inches) lose in ultimate strength from 5,000 to 10,000 pounds per square inch, and quite notably in elastic limit also. This loss has no definite relation to the size of the bar, and it is impossible to predict how much a bar of a certain size will loose.

Theodore Cooper.

Theodore Cooper while testing some steel links for Keystone bridge in 1878 noticed peculiar marks upon the link heads due to cracking of the scale under the test. He took this phenomena in a number of tests following the above mentioned as indication of the development of stress at the place of cracking. Attempts to use some resinous coatings were only partially successful.

The results of the steel links test proved that the lines of greatest shear are at the angles of 45 degrees to the applied force.

Twenty eight years later working on the design of the Quebec bridge Mr. Cooper performed a number of tests on the steel eye-bars, mainly for the purpose of determining the effect of the pin clearance.

Incidently he observed the following new facts about the steel bars:

1) Real elongation of an eye-bar is from out to out of pin holes, and not from center to center of pins.

2) No definite results could be obtained to determine the effect of the

pin clearances.

3) Influence of the percentages of excess of the head is indeterminded.

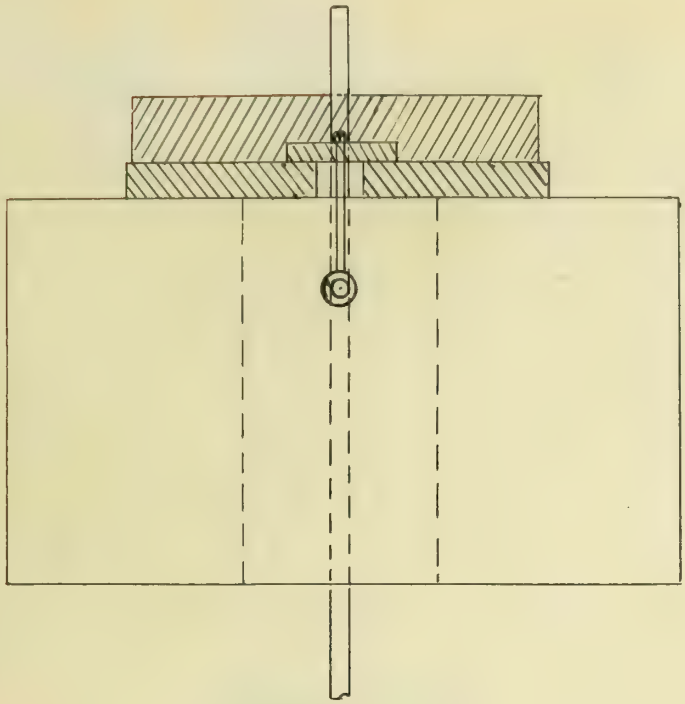
Materials, Apparatus and Method of Testing

The eye-bars which were tested were obtained from the Wabash Railroad. They were formerly used in the bridge over the Sangamon river, south of Decatur. The bridge was changed from deck to through type and some of the eye bars were left over.

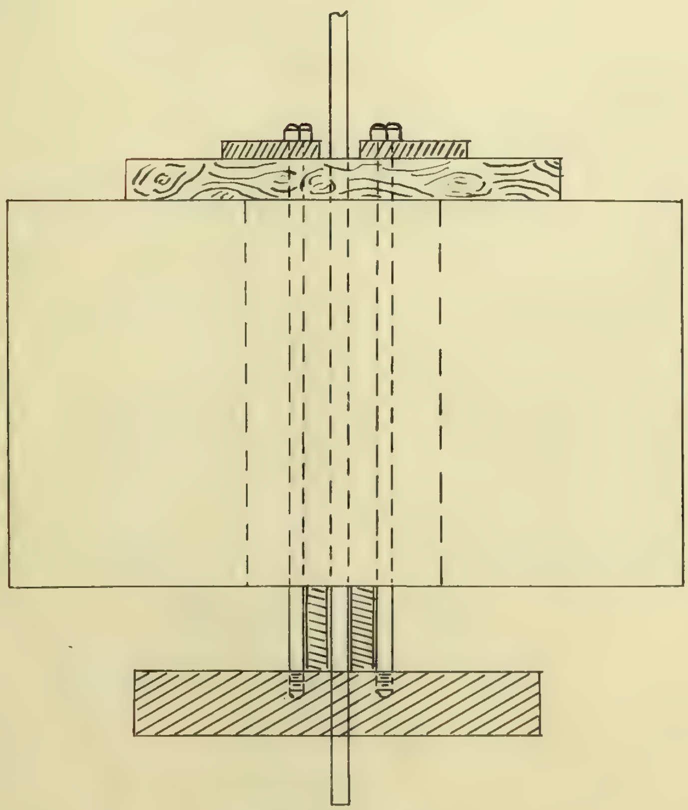
As far as known, the bridge was in good condition, and the wrought iron used for the eye-bars represents standard practice when the bridge was erected. The lengths of the bars were about $14\frac{1}{2}$ feet from center to center of pin, all having about 6 square inches cross section, and 4 inch pin hole. Outlines of the heads of the eye-bars are given in figures 5 to 13, and dimensions in table

The Riehle vertical screw testing machine of 600,000 pounds capacity in the Laboratory of Applied Mechanics of the University of Illinois was used for testing the pieces. The method of fixing the bars in the machine is shown in figures 1 and 2. A 40 inch gauge extensometer shown in figure 3 on riveted joints

Figure 1

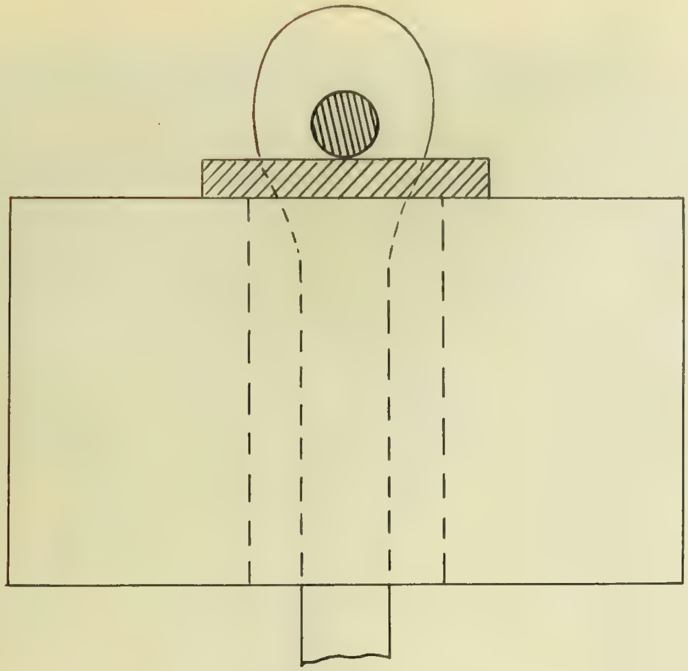


Upper Head

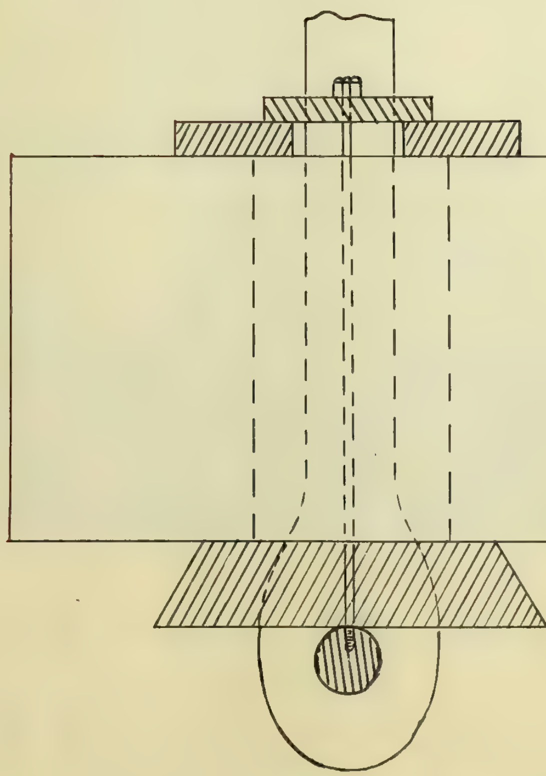


Lower Head

Figure 2

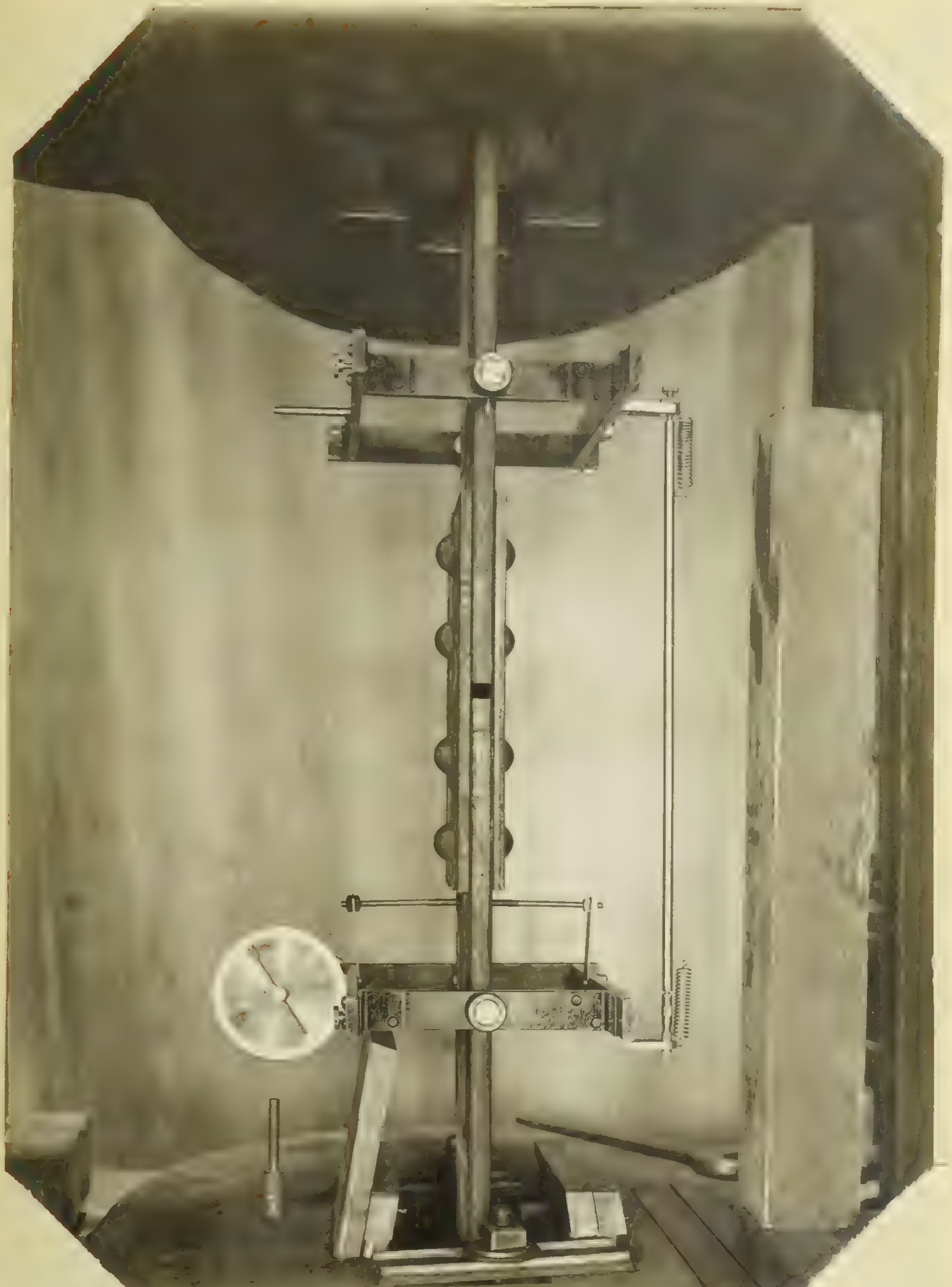


Upper Head



Lower Head

Figure 3

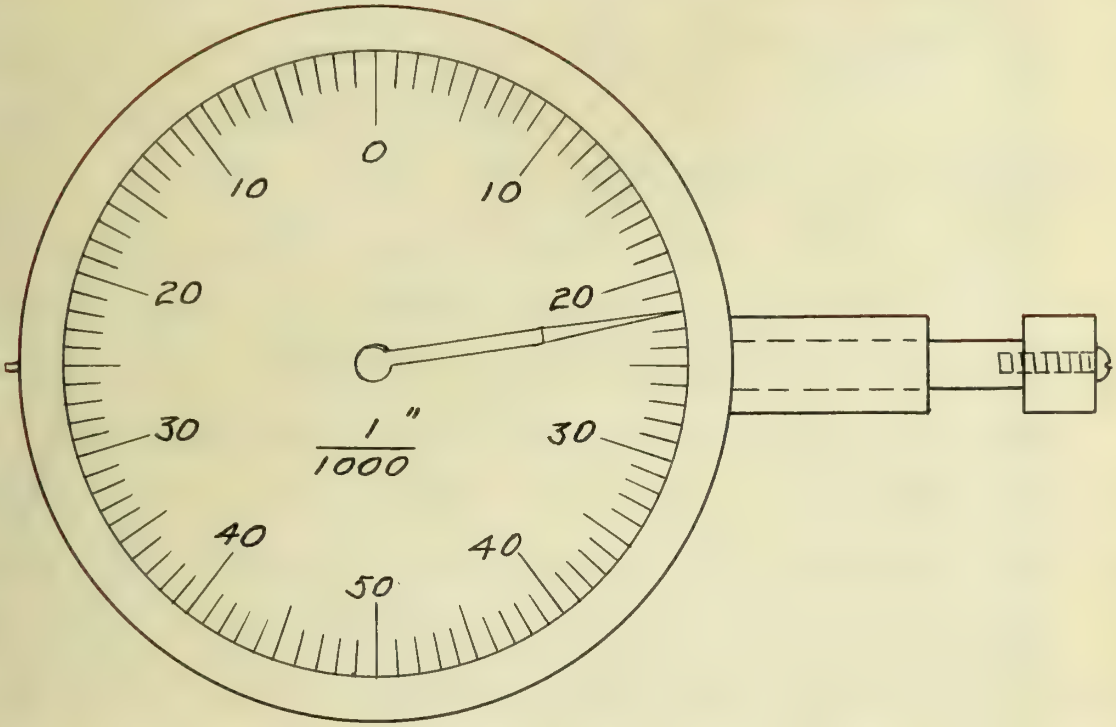


was used on all tests. It was attached to the middle portion of the bar, and recorded the elongations in ten-thousandths of an inch.

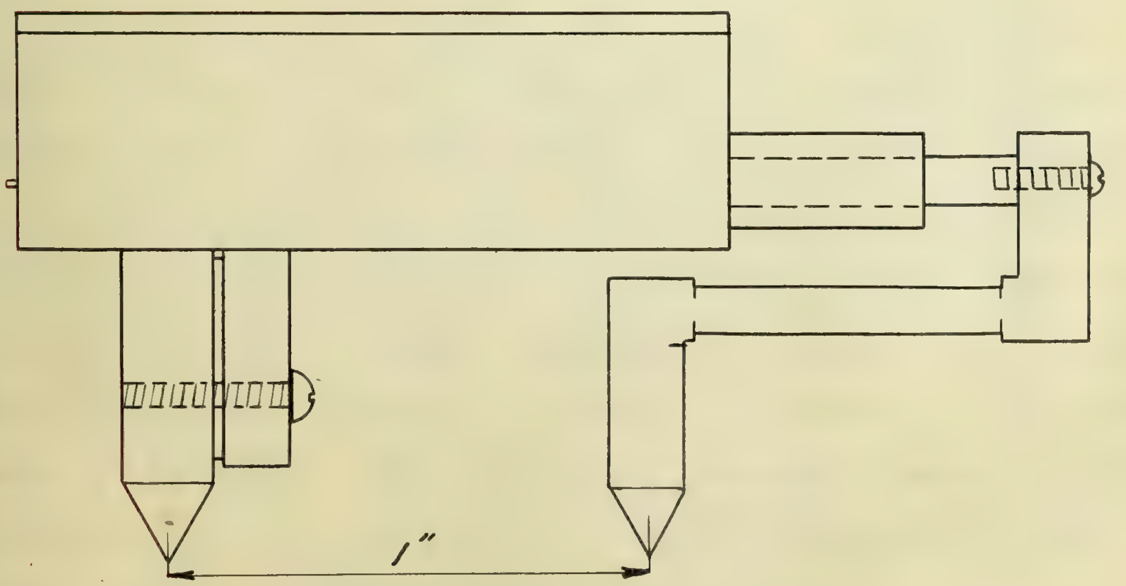
Two methods were used for testing the heads of the bars. The first method consisted in cross-ruling the heads into one inch squares, and measuring the elongation or shortening of the sides of the squares by means of an extensometer shown in figure 4. This work proved very laborious as well as inaccurate. In order to estimate the distribution of stresses in the head a very large number of readings had to be taken for each increment of load. As the loads became large the holes for setting the extensometer stretched to such an extent that accurate readings could not be obtained. On account of these difficulties this method was abondoned after the first test was performed.

The second method, which was followed throughout the rest of the tests, consisted in coating the surface of the eye bars with Plaster of Paris whitewash, mixed thin and put on with a brush, and observing the distribution of the stresses

Figure 4



PLAN



ELEVATION

by the scaling of the whitewash. The location of scaling was permanently fixed by stamping with steel dies the figures showing in thousands of pounds the load at which the scaling took place.

After the first test was performed it was observed that in that test the yield point was first developed in the body of the bar. Since the main object of the test was to investigate the distribution of the stresses in the head it was decided to weaken some of the heads artificially. This was done by reducing the section of one head of each bar as shown in figures 5 to 13, thus making the yield point to develop in the head first.

Specimens for tension tests were cut out from the least stressed portion of the bar under the pin hole as shown in figures 5 to 13. Two specimens were tested from each eye-bar one being taken from the upper and the other from the lower head. These specimens were tested for yield point and ultimate stresses in tension. The results of the tests are shown in table IV

Figure 5

Figure 6.

Figure 7

Figure 8

Figure 9

Figure 10

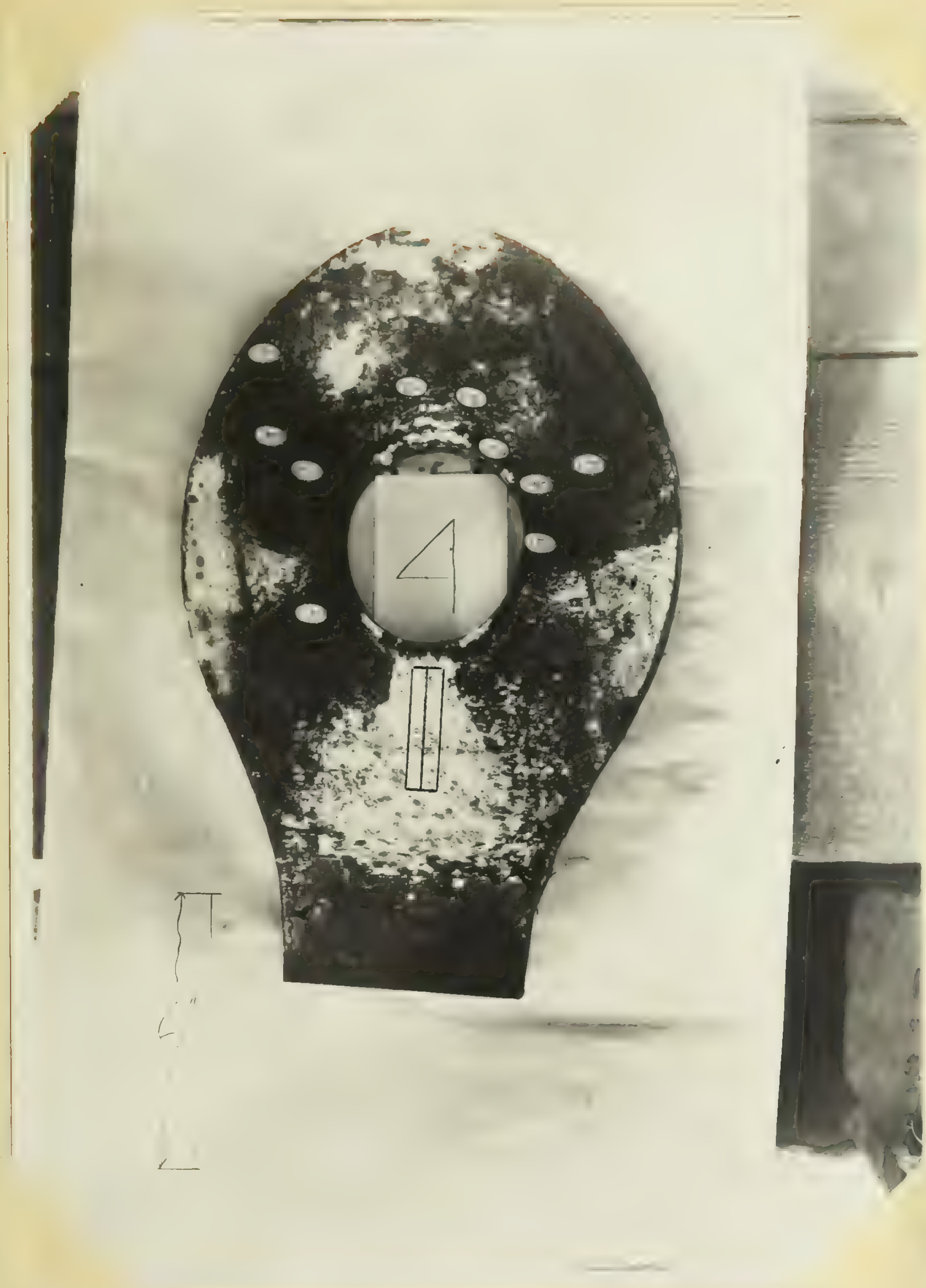


Figure 11

Figure 12

Figure 13

TABLE I

Schedule and Dimensions of Eye-Bars Tested

Test No.	Length c. to c. of Pin Holes Ft.-In.	Thickness Inches	Width Inches	Area of Cross-Section Sq. In.	Diameter of Pin Hole Inches	Width of Head Inches		Remarks
						As received	Reduced	
1	$14\text{-}3\frac{3}{4}$	0.99	6.05	6.00	4	12.25		Extensometer Test No Reduced Head
2	$14\text{-}4\frac{1}{2}$	1.04	6.00	6.24	4	12.25	10.50	Coated with Plaster Paris White Wash
3	$14\text{-}3\frac{7}{8}$	1.19	5.00	5.94	4	11.25	9.25	"
4	14-4	1.13	5.00	5.63	4	11.00	11.00	"
5	$14\text{-}7\frac{3}{4}$	1.25	4.94	6.18	4	11.25	11.25	"
6	$14\text{-}3\frac{7}{8}$	1.00	6.00	6.00	4	12.25	10.50	"

TABLE II

Moduli of Elasticity from Tests of Full Sized Eye-Bars

Test No	Moduli of Elasticity
1	
2	27 900 000
3	27 900 000
4	30 000 000
5	26 600 000
6	28 900 000

TABLE III

Average Stresses in Eye-Bars at Yield Point

Test No.	Yield Point			Remarks
	In Body Lbs. per Sq. In.	In Reduced Head Lbs. per Sq. In. of Body	In Head as Received Lbs. per Sq. In of Body	
1				No Reduced Head Bar not Broken
2	14 700	14 100	19 250	Broke in Reduced Head Oval Shaped Head
3	24 850	19 200	19 200	" " "
4	26 250	18 150	24 500	Broke in Body Circular Reduced Head
5	25 200	17 500	23 300	" " "
6	21 150	17 200	23 300	Broke in Reduced Head Oval Shaped Head

TABLE IV

Comparative Data on Specimens and Full-Sized Bars.

Test No	Specimens					Full-Sized Bars		$\frac{S}{s}$	$\frac{P}{p}$
	Head	Elongation Percent in 2 Inches	Reduction of Area Percent	Yield Point "P" Lbs per Sq. In.	Ultimate "S" Lbs per Sq. In.	Yield Point "p" Lbs. per Sq. In. in Body	Ultimate "s" Lbs per Sq. In. in Body		
1	U_1	19.0	66.5	37 900	45 800		32 350	1.42	
	L_1	16.5	80.0	31 100	45 700			1.41	
2	U_2			37 500	37 600*	14 700	33 800†	1.11	2.55
	L_2	21.5	64.5	36 800	47 500			1.41	2.50
3	U_3	13.5	70.9	51 000	54 400	24 850	34 900†	1.56	2.05
	L_3	21.0	61.3	40 300	50 800			1.46	1.62
4	U_4	18.0	74.1	41 600	50 200	26 250	42 800	1.17	1.59
	L_4	16.5	77.7	42 500	50 500			1.18	1.62
5	U_5	12.5	74.2	36 300	47 800	25 200	40 150	1.19	1.44
	L_5	24.0	74.2	34 600	51 300			1.28	1.37
6	U_6	28.0	68.1	36 400	47 500	21 150	34 900†	1.36	1.72
	L_6	11.5	80.3	44 800	46 800			1.34	2.12

* Failed at Yield Point.

† Broke in Head

TABLE V

Ratios of Load at Yield Point in the Head to That in the Body and of Width of the Head to Diameter of Pin.

Test No.	Load at Yield Point in Head "P_2" Pounds	Load at Yield Point in Body "P_1" Pounds	$\frac{P_1}{P_2}$	Diameter of Pin Hole "d" Inches	Width of Head "D" Inches	$\frac{D}{d}$
1 1*				4	12.25	3.06
2 2*	120 000 88 000	91 700	0.764 1.04	4	12.25 10.50	3.06 2.62
3 3*	134 000 114 000	147 300	1.10 1.29	4	11.25 9.25	2.82 2.31
4 4*	138 000 108 000	148 000	1.07 1.37	4	11.00 11.00	2.75 2.75
5 5*	144 000 144 000	155 300	1.08 1.08	4	11.25 11.25	2.81 2.81
6 6*	140 000 103 000	126 800	0.906 1.23	4	12.25 10.50	3.06 2.62

*Reduced Head

TABLE VI

Ratio of Load at Ultimate Stress of the Eye-Bar to Ultimate Stress of the Material.

Test No.	Load at Ultimate in Eye-Bar "P_2" Pounds	Load at Ultimate in Test Specimen "S" Pounds per sq. in.	Cross-Section of Body of Bar "a" Sq. In.	Sa = "P_1"	$\frac{P_1}{P_2}$	Diameter of Pin Hole "d" Inches	Width of Head "D" Inches	$\frac{D}{d}$
1	193800	45800	6.00	275000	1.42	4.0	12.25	3.06
1*		45700		274000	1.42		12.25	3.06
2	211000†	37600	6.24	234000	1.11	4.0	12.25	3.06
2*		47500		296000	1.40		10.50	2.62
3	207200†	54400	5.94	323000	1.56	4.0	11.25	2.82
3*		50800		302000	1.46		9.25	2.31
4	241000	50200	5.63	283000	1.18	4.0	11.00	2.75
4*		50500		284000	1.18		11.00	2.75
5	247600	47800	6.18	296000	1.20	4.0	11.25	2.81
5*		51300		317000	1.28		11.25	2.81
6	209200†	47500	6.00	285000	1.36	4.0	12.25	3.06
6*		46800		281000	1.34		10.50	2.62

* Reduced Head
† Broke in Head

Discussion of Results.

The results of this thesis can not be taken to prove or disprove any definite theory in regard to the distribution of stresses in the eye-bar heads, but they may be used as indication of certain factors worthy of consideration.

In most of the eye-bars tested it was observed that the yield point first occurred in the head, while the ultimate stress was reached first in the body. This fact may be taken as an indication of certain readjustment of stresses, and is very likely due to the change in condition of material in portions of stress beyond the yield point.

Very definite conclusions can be reached in regard to the points of maximum stress in the heads of the bars tested. As it can be seen from the photographs the first scaling invariably took place along the lines of about 45 degrees to the axis of the bar, showing that these portions carried the greatest shear. This agrees with the theoretical determination of Mr. W. H. Burr, and with the results of Mr. Theodore Cooper's link heads test.

The position of minimum stress apparently lies directly under the eye as indicated by almost total absence of scaling at that place.

It can be seen from the table IV of comparative strengths of full sized eye-bars and small specimens that the yield point and ultimate strength of the wrought iron in the eye bars tested are about the average of those expected from wrought iron. The large discrepancies in the yield point are probably due to the fact that the material was stressed beyond the yield point before the present tests were undertaken.

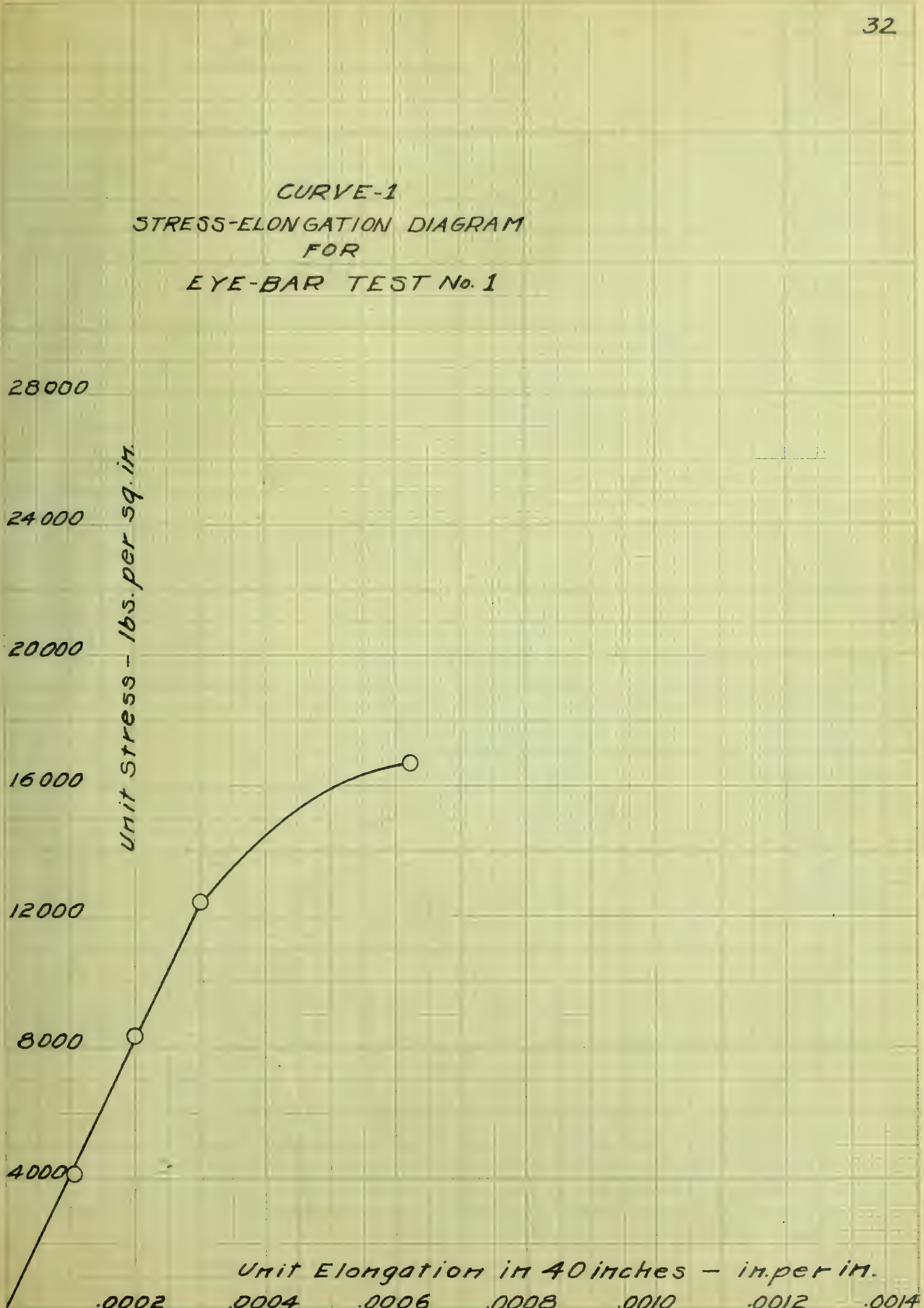
In regard to the comparative strength of the full sized bars and test specimens it can be safely said that the small specimens are capable of carrying a considerably larger stress than the full sized eye bars. On the average the stresses developed in the test specimens are from 70 to 80 percent higher at yield point and from 30 to 35 percent at the ultimate than are the stresses in the full sized bars. This agrees with the results of the experiments performed

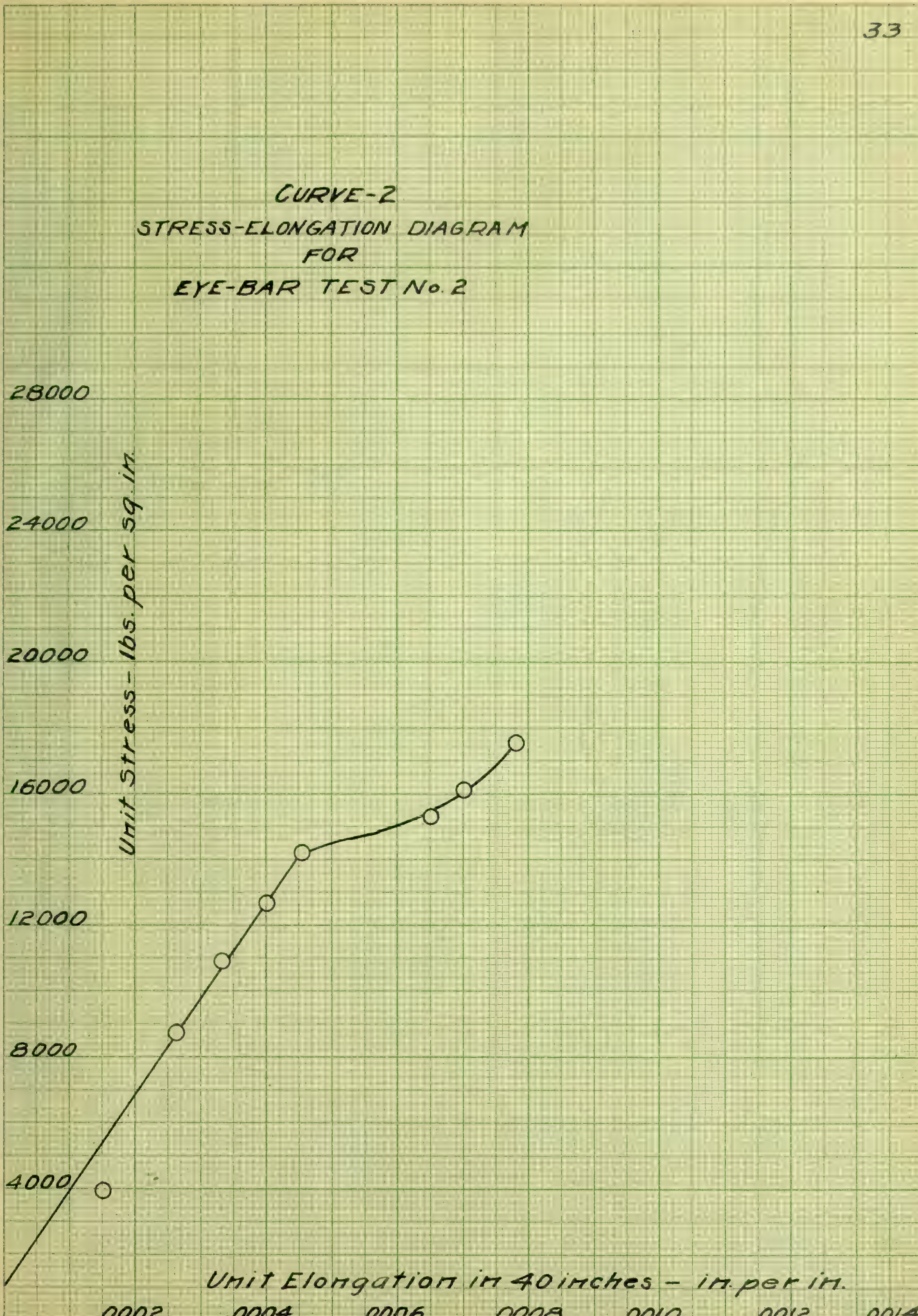
by Mr. Frederick H. Lewis.

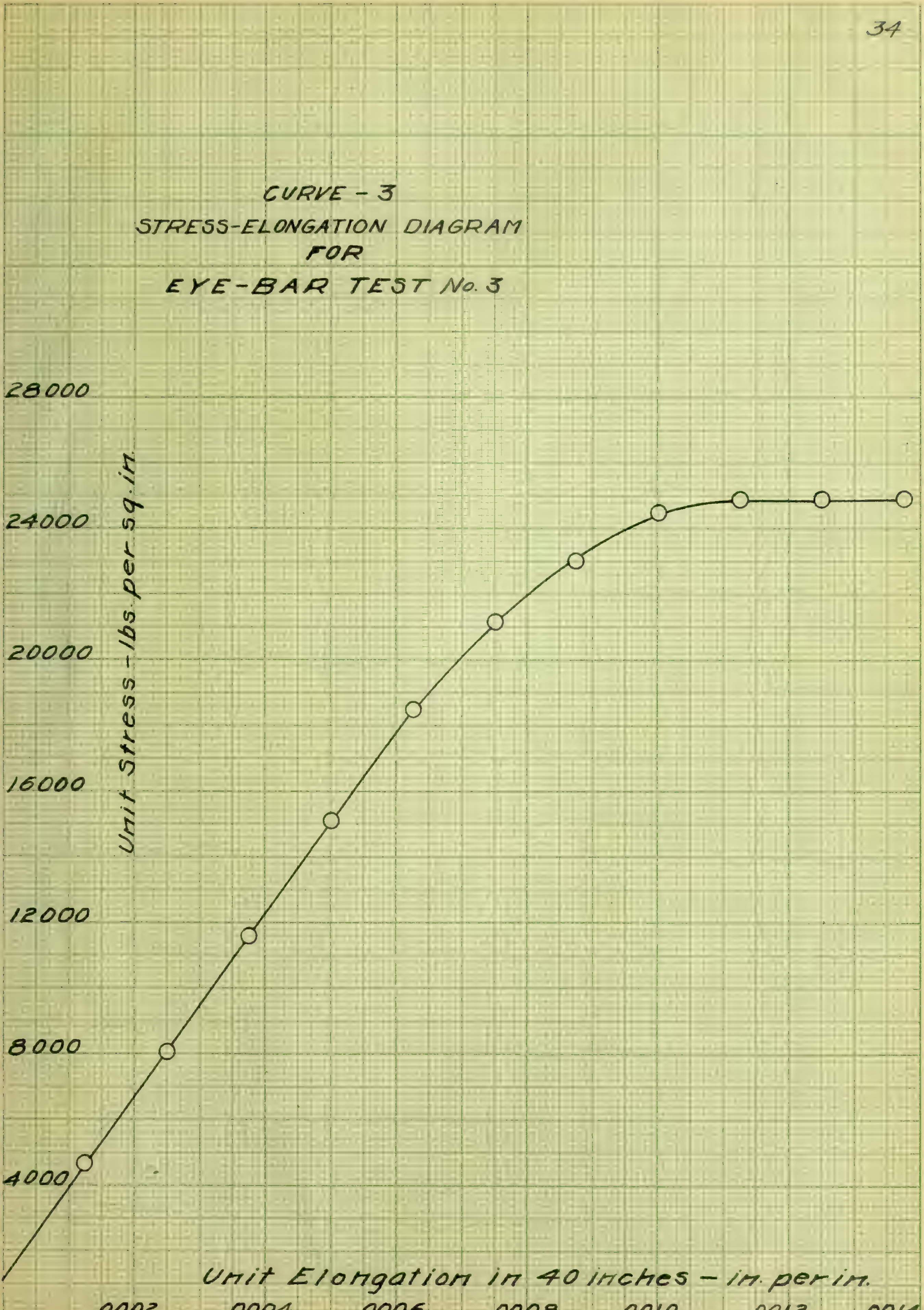
An attempt was made to establish the proper ratio between the width of the head and the diameter of the pin based on the stresses at the elastic limit. From curve 7 it can be seen that, in order to have the elastic limit occur at the same time in the body and in the head, the ratio of the width of the head to the diameter of the pin should be about 2.9

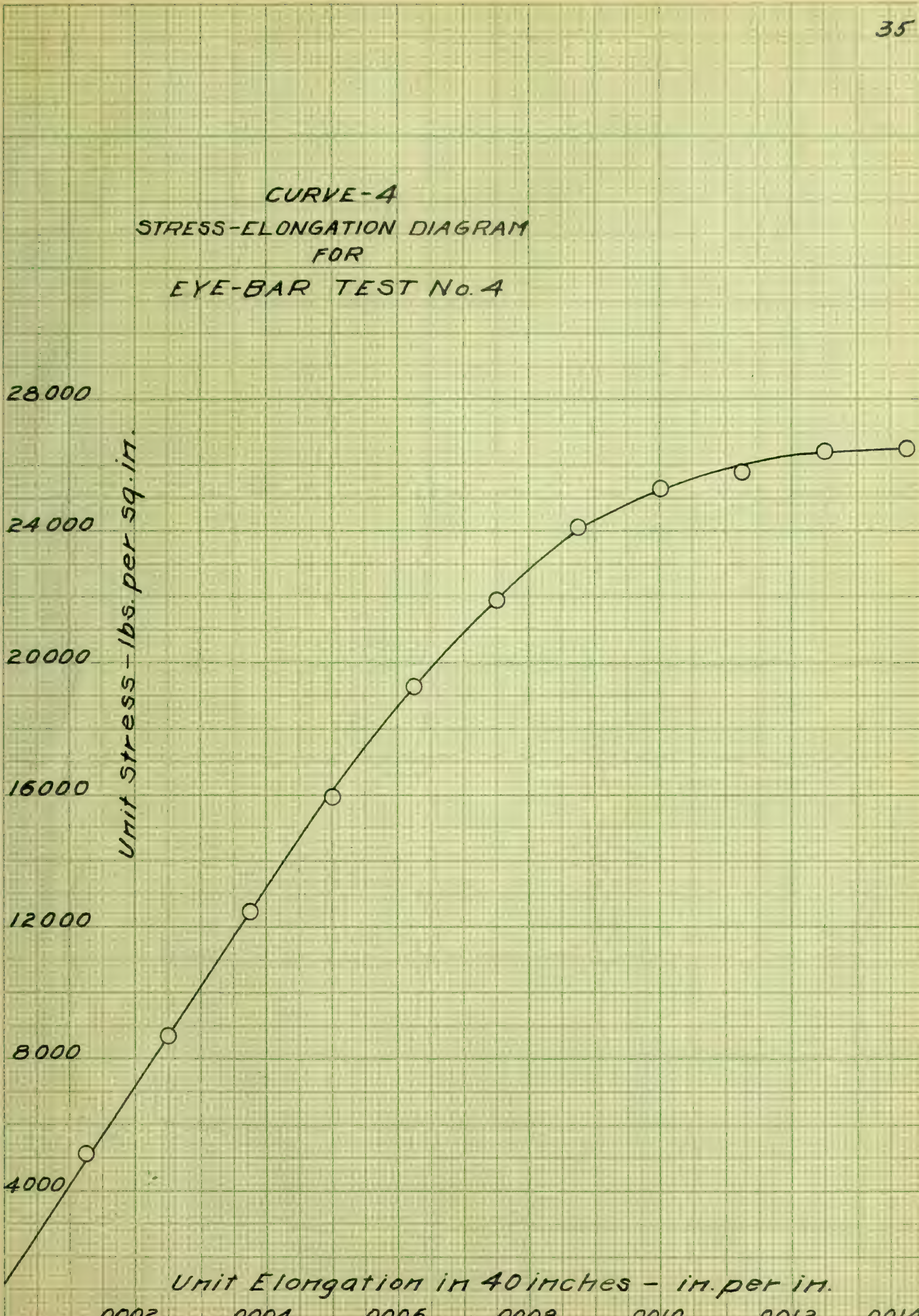
Curve 8 shows that no definite results could be obtained to establish the same ratio on the basis of the stresses at the ultimate.

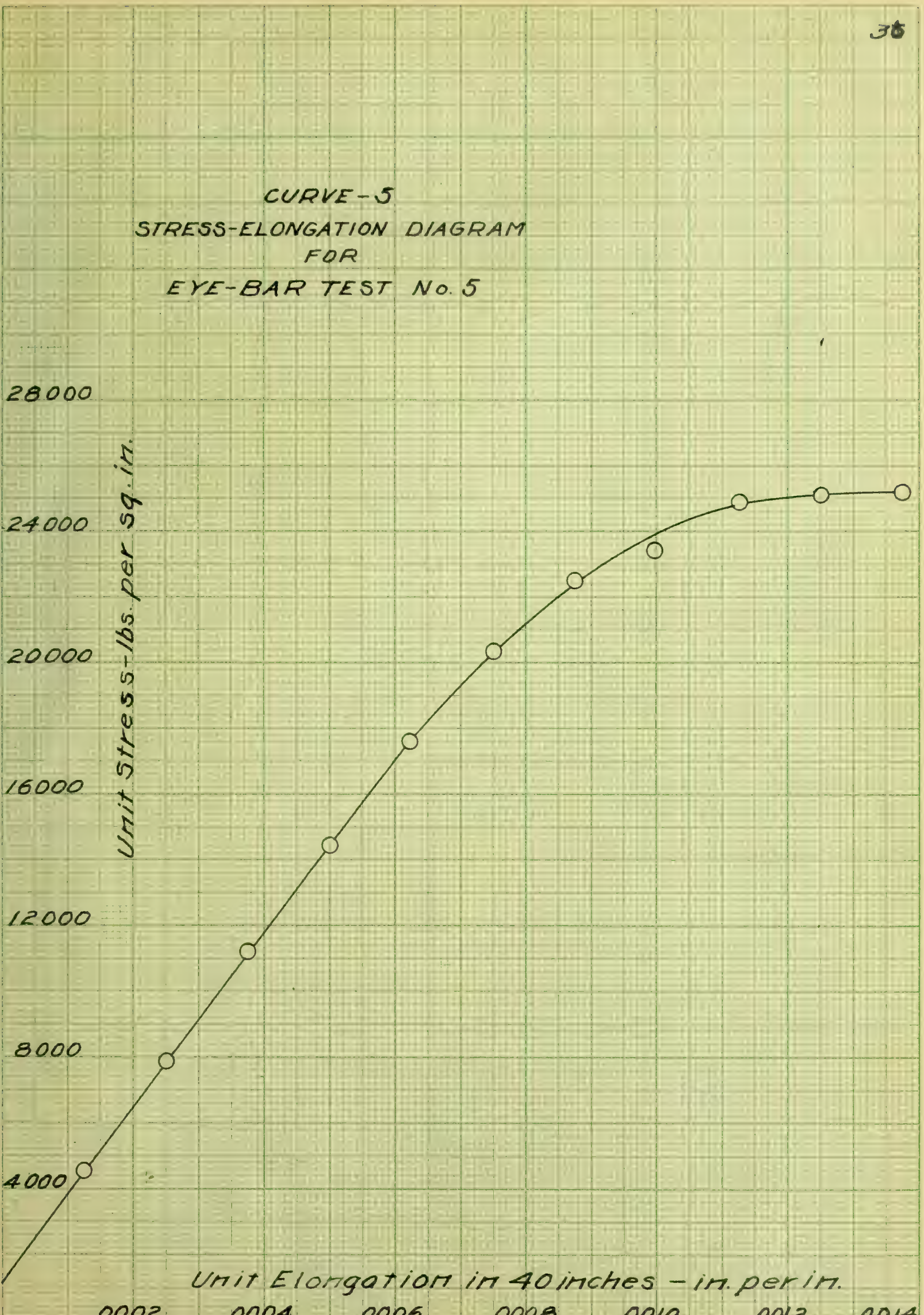
Incidentally the test of eye-bars illustrated a good method of studying the distribution of stresses by scaling of the whitewash.


CURVE-1
STRESS-ELONGATION DIAGRAM
FOR
EYE-BAR TEST No. 1
28000
24000
20000
16000
12000
8000
4000
Unit Stress - lbs. per sq. in.
Unit Elongation in 40 inches - in. per in.
.0002
.0004
.0006
.0008
.0010
.0012
.0014

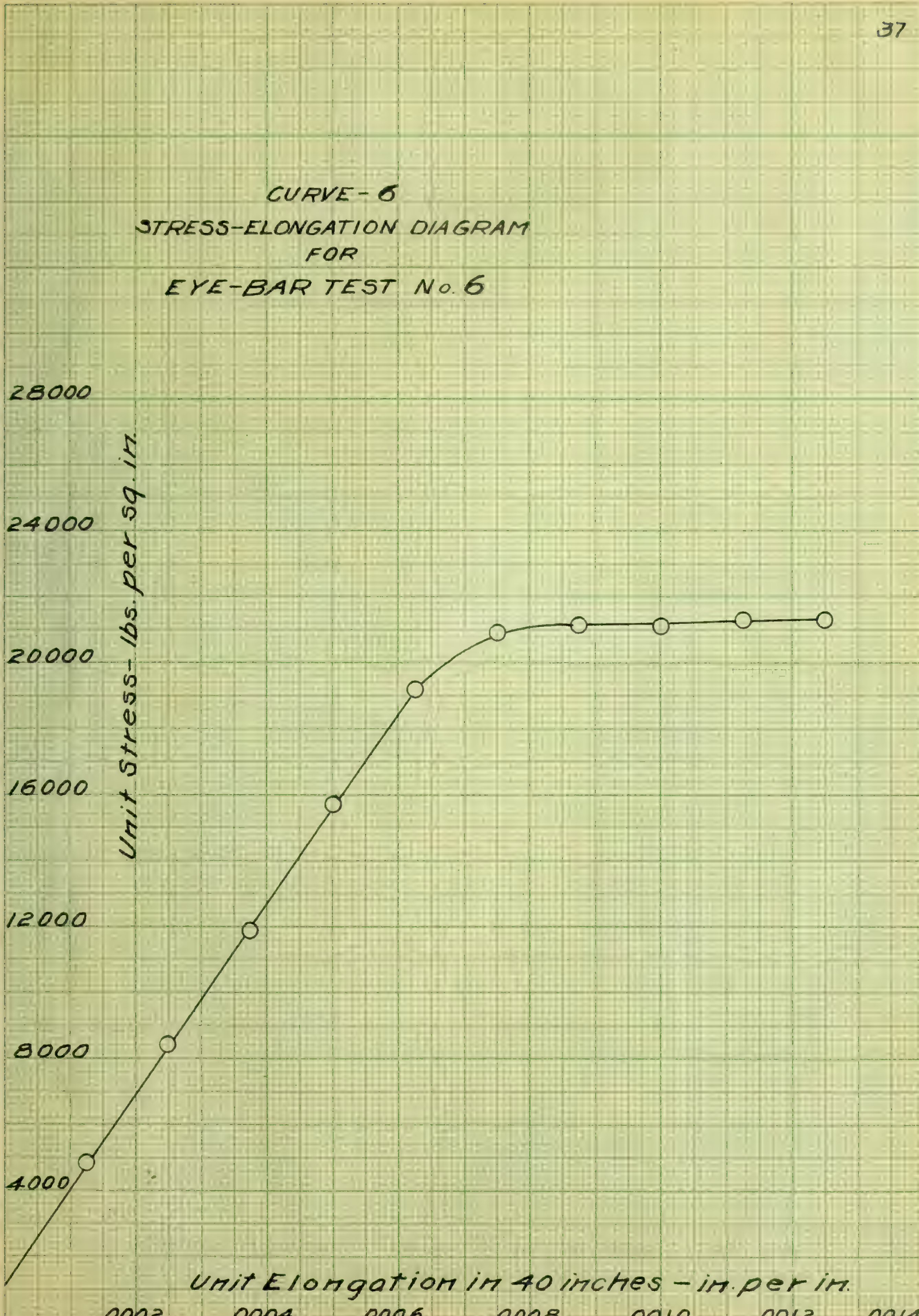

CURVE-2
STRESS-ELONGATION DIAGRAM
FOR
EYE-BAR TEST No. 2
28000
24000
20000
16000
12000
8000
4000
Unit Stress - lbs. per sq. in.
Unit Elongation in 40 inches - in. per in.
.0002
.0004
.0006
.0008
.0010
.0012
.0014
U. OF I. S. S. FORM 3


CURVE - 3
STRESS-ELONGATION DIAGRAM
FOR
EYE-BAR TEST No. 3
28000
24000
20000
16000
12000
8000
4000
Unit Stress - lbs. per sq. in.
Unit Elongation in 40 inches - in. per in.
.0002
.0004
.0006
.0008
.0010
.0012
.0014

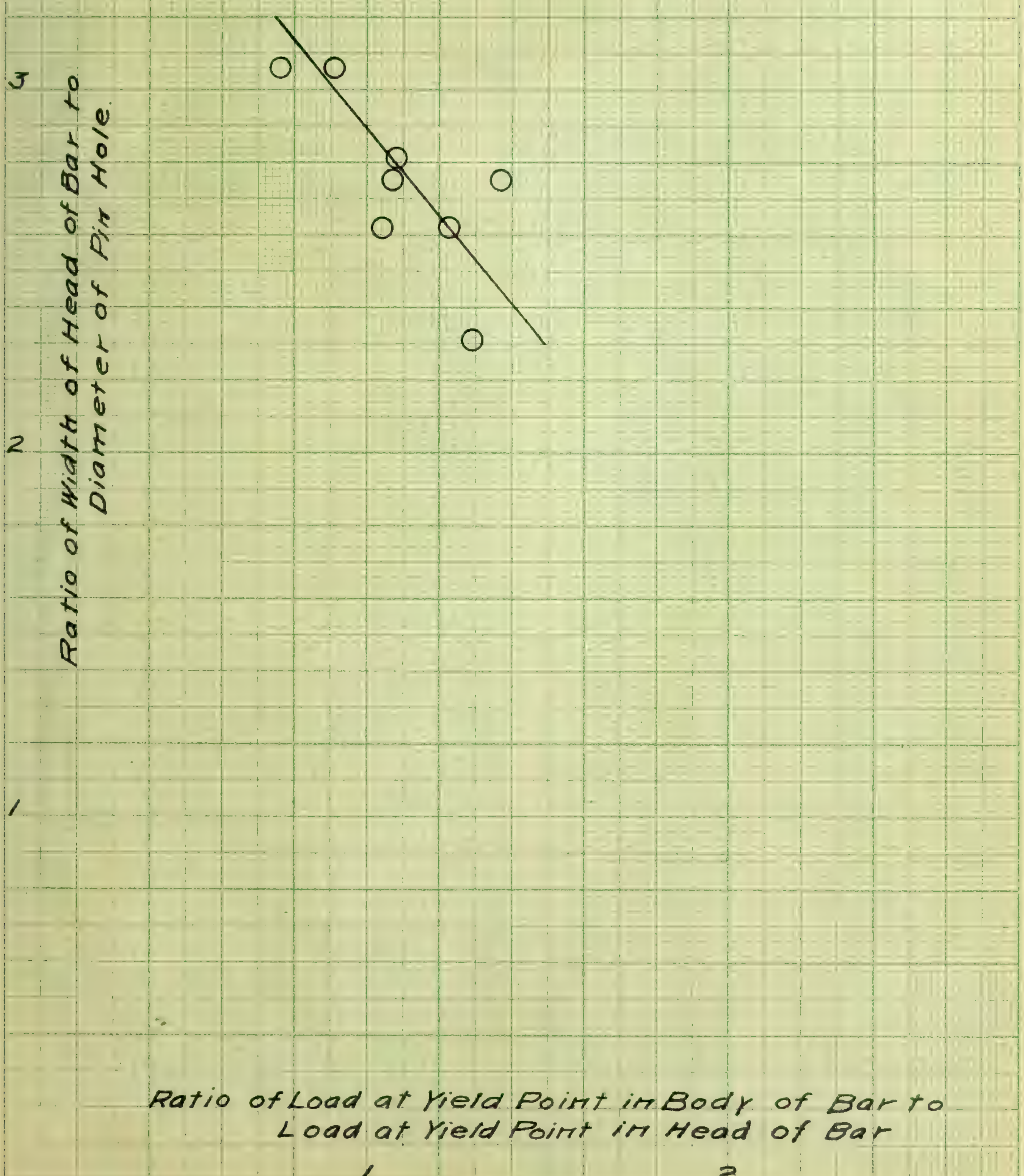

CURVE-4
STRESS-ELONGATION DIAGRAM
FOR
EYE-BAR TEST No. 4
Unit Stress - lbs. per sq. in.
28000
24000
20000
16000
12000
8000
4000
Unit Elongation in 40 inches - in. per in.
.0002
.0004
.0006
.0008
.0010
.0012
.0014
U. OF I. S. S. FORM 1



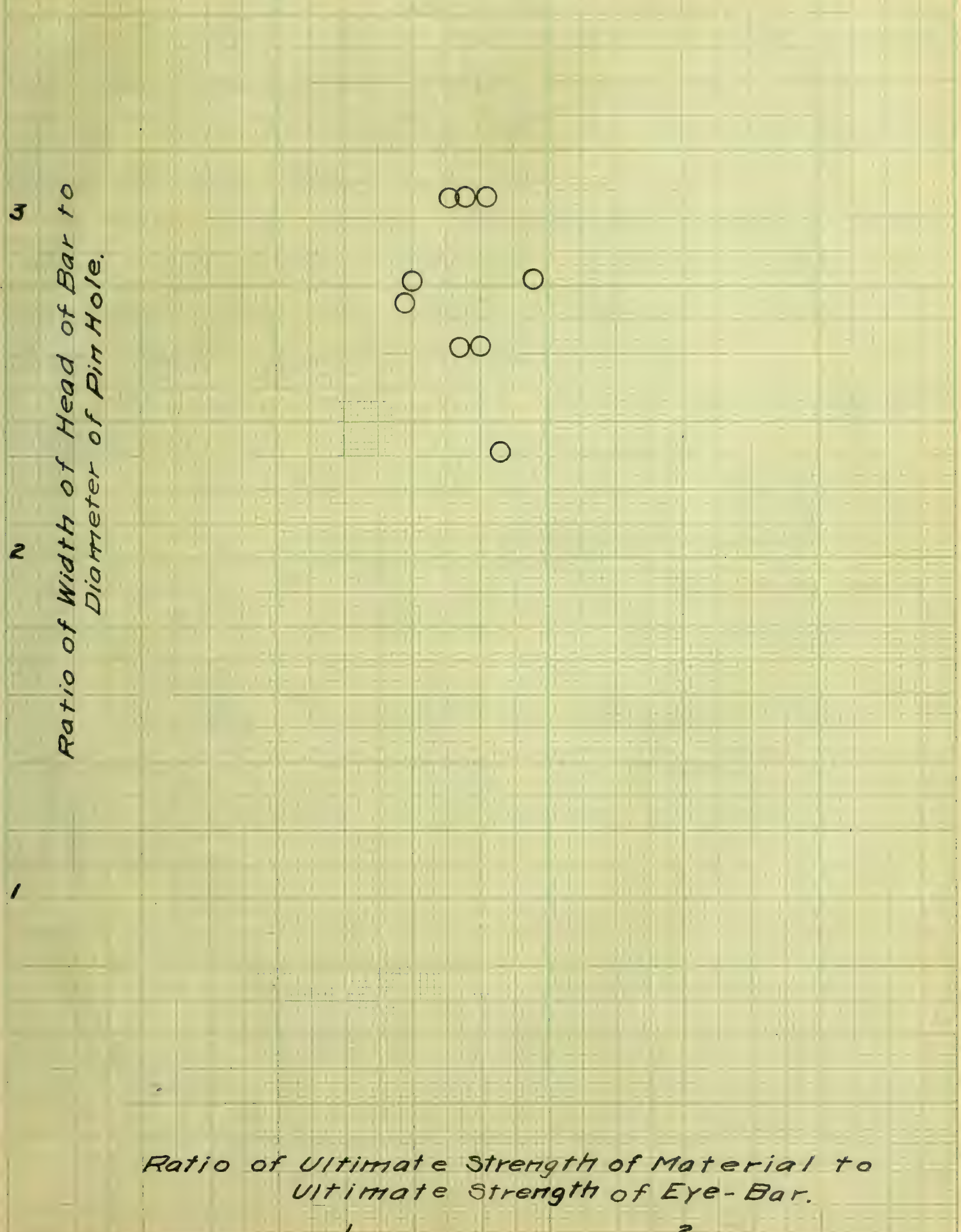
CURVE-5
STRESS-ELONGATION DIAGRAM
FOR
EYE-BAR TEST No. 5
Unit Stress-lbs per sq. in.
28000
24000
20000
16000
12000
8000
4000
Unit Elongation in 40 inches - in. per in.
.0002
.0004
.0006
.0008
.0010
.0012
.0014


CURVE - 6
STRESS-ELONGATION DIAGRAM
FOR
EYE-BAR TEST No. 6
28000
24000
20000
16000
12000
8000
4000
Unit Stress - lbs. per sq. in.
Unit Elongation in 40 inches - in. per in.
.0002
.0004
.0006
.0008
.0010
.0012
.0014

CURVE – 7


Ratio of Width of Head of Bar to Diameter of Pin Hole
3
2
1
Ratio of Load at Yield Point in Body of Bar to Load at Yield Point in Head of Bar
1
2

CURVE-8


Ratio of Width of Head of Bar to Diameter of Pin Hole.
3
2
1
Ratio of Ultimate Strength of Material to Ultimate Strength of Eye-Bar.
1
2

Conclusions

1) The maximum stress in the heads of the eye-bars tested occurred along lines approximately at 45 degrees to the axis of the bar.

2) The unit stresses at yield point and ultimate strength are considerably greater for the test specimens than for the full sized eye-bars.

3) Tests did not show any considerable deterioration in wrought iron.

4) For the wrought iron eye-bars tested the most economical ratio of the width of the head to the diameter of the pin as based on the stresses at the yield point is about 2.9.

5) The method of studying the distribution of stresses by means of scaling of the whitewash is fairly satisfactory.